AN APPARATUS FOR REMOVING ECHO FROM SPEECH SIGNALS WITH VARIABLE RATE

Field of the Invention

The present invention relates to an echo canceler of a variable rate vocoder, and more particularly to an echo canceler and a method for preventing undesirable disturbance of converged filter coefficients.

Background of the Invention

Echo cancelers have recently gained importance with the increased usage of CDMA (code division multiple access) in mobile telephony. Echo signals are present in a digital telephone connection. The echo signals distort or disturb speech signals generated from the two ends of the connection. Echo cancelers are used to cancel the echo signals. However, a long delay time is necessary in such cancellation. The delay time required to cancel the echo signal by the echo canceler is called 'convergence time'. The convergence time of the echo canceler is an important parameter for measurement of the quality of the echo canceler. The smaller the convergence time, the closer is the reproduction of the original sound.

Adaptive algorithms are used in echo cancelers. One popular algorithm is the NLMS (normalized least mean square) algorithm. A filter is used to cover practically all occurrences of impulse responses. A filter output signal is conventionally subtracted from the signal containing an echo, thereby forming a different signal used to update the filter. U. S. Patent No. 5,428,605

describes a prior art echo canceler and it is shown in Figs. 1 and 2.

A plurality of filters 14_1-14_N for canceling out an echo signal are connected in cascade between two lines RX and TX included in a four-wire loop. The echo signal emerges in an echo path 12 from speech signals of a called person or a calling person of a telephone call connection. The filters 14_1-14_N act as a digital adaptive filter. They receive an input signal X through a line RX. The input signal X is applied to the echo path 12.

An echo signal is decided through each of output signals Y_1-Y_N of the filters 14_1-14_N. An echo signal is cancelled from an echo-included signal D through subtraction means 24. Consequently, each of the subtraction means outputs each of difference signals E_1-E_N. The filters 14_1-14_N update filter coefficients with correspondence to an adaptive algorithm by receiving the different signals E_1-E_N.

The filters 14_1-14_N receive the input signal X and then generate the output signals Y_1-Y_N, respectively. The output signals Y_1-Y_N are applied to a plurality of selectable switches 16_1-16_N. The switches 16_1-16_N are connected to subtraction means 18_1-18_N, respectively. That is, the switches 16_1-16_N are connected to negative input terminals of the subtraction means 18_1-18_N, respectively. Positive input terminals of the subtraction means 18_1-18_N receive an echo-reduced signal 26 which is obtained by reducing the echo signal from the echo-included signal D. The switches 16_1-16_N also receive selective signals S_1-S_N, respectively. Accordingly, the subtraction means 18_1-18_N output the different signals E_1-E_N, respectively. The selective signals S_1-S_N are generated from a switch control circuit 30 shown in Fig. 2 to select at least one of the filters 14_1-14_N. The switch control circuits 30 will be described hereafter. An output signal Y_N of a filter to which corresponding switch is connected to the right side output terminal is not used to cancel an echo signal. However, the output signal Y_N is used to output an error signal E_N which is in turn

used to update the filter.

An error signal is a difference between the echo-reduced signal 26 and a filter output signal provided through a switch which is switched to its right side output terminal. For example, error signals E_2 and E_N in Fig. 1 are such error signals.

In the initial stage of a converging process such as the beginning of a new telephone call, all switches are switched to the switching terminals on the right side. The following error signals are thereby obtained: E_1=D-Y_1, E_2=D-Y_2, ---,E_N=D-Y_N. This is resulted from an equal supply of the echo-included signal D to the positive input terminals of the subtraction means 18_1-18_N in the initial stage, respectively. This signal is called an echo-reduced signal E_{TOT}.

In the initial stage (that is, before enabling filters to use actively to cancel an echo), the filters adjust in an endeavor to cancel the total echo signal. In this case, the filters are converged into a certain level, respectively. Since a filter among the cascade-connected filters is generally disturbed by some part of the total echo signal, the echo signal is actually canceled by one and more filters of the other filters.

The quality measurement of an adaptive filter is continuously calculated in order to be able to establish which filters perform useful work. In other words, the quality measurements and values are used to form switch control signals. When the quality measurement of a filter exceeds a predetermined value, the filter renders the corresponding switch switched to its left switching position.

When the measurement resultant is lower than the predetermined value, the filter is disabled so as for the corresponding switch to be switched to its right switching position. An output signal of the filter is added in an adding means to other output signals of the filter which are added in other adding means, respectively. The resultant summation signal is subtracted from

the echo-included signal D in subtraction means 24. For example, the filters 14_1-14_{N-1} are enabled to reduce the echo signal appeared in the echo-included signal D. An output signal of the enabled filter is summed to be Y_1+Y_{N-1}, and an echo-reduced signal E_{TOT} becomes equal to: $D-(Y_1+Y_{N-1})$. These are subtracted from the echo-included signal D by a plurality of cascade-connected subtraction means, respectively.

Since the output signals of the enabled filters do not appear on the input signals of the subtraction means, all enabled filters will obtain error signals equally as large as the echo-reduced signal E_{TOT}. The error signal of the disabled filter is equal to the echo-reduced signal E_{TOT} decreased by the output signal of the filter. In the illustrated example, the [Equation 1] is obtained:

[Equation 1]

$$E_1 = E_{TOT} - Y_1 = D-(Y_1+Y_{N-1})$$

$$E_2 = E_{TOT} - Y_2 = D-(Y_1+Y_2+Y_{N-1})$$

$$E_N = E_{TOT} - Y_N = D-(Y_1+Y_{N-1}+Y_N)$$

Therefore, when a filter is enabled, its output signal will be used to update the remaining filters. It is the fact that every enabled filter receives large error signals. Every error signal of these filters can be caused to go down to logic 0 or to the vicinity of logic 0 by effectively canceling the echo signal. Accordingly, none of the filters will be disturbed by any part of the total echo that shall be canceled by other filters.

Fig. 2 illustrates an arrangement of a switch control circuit generating a switch control signal illustrated in Fig. 1. Referring to Fig. 2, the switch control circuit 30 is required for each

filter 14_1-14_N included in the echo canceler 10.

The echo-reduced signal E_{TOT}, the filter output signal Y_N, and the filter error signal E_N are applied to the switch control circuit. Some signals are generated from absolute magnitude forming means 32_1, 32_2, and 32_3. Each of the signals is then filtered in its respective lowpass filter means (LPF) 34_1, 34_2, and 34_3. Signals deriving from the echo-reduced signal E_{TOT} and the filter output signal Y_N are multiplied in a multiplier 36, so that a signal $|E_{TOT}|*|Y_N|$ is generated. A signal deriving from a lowpass filter 34_3 of the filter error signal E_N is squared in a quadrating means 38, so that a signal $|E_N|*|E_N|$ is generated.

The signal from the multiplier 36 is divided by the signal from the quadrating means 38 in a division means 40. The quality measurement Q_N is generated from the division means 40 and its equation is as follows:

[Equation 2]

$$Q_N = (|E_{TOT}|/|E_N|)*(|Y_N|/|E_N|) = (|E_{TOT}|*|Y_N|)/(E_N*E_N)$$

According to [Equation 2], the quality measurement Q_N is proportioned to the output signal Y_N. When the quality measurement Q_N exceeds a first threshold value Tr1, the switch control signal S_N goes to logic 1. When the quality measurement Q_N becomes lower than a second threshold value Tr2, the switch control signal S_N goes to logic 0. In this case, when the switch control signal S_N is logic 1, the switch is connected to its left switching position.

The quality measurement Q_N is used as input signals of a first comparator 42_1 and a second comparator 42_2. That is, the quality measurement Q_N is compared in the first comparator 42_1 with the first threshold value Tr1 of the filter enabled, while in the second comparator 42_2

with the second threshold value Tr2 of the filter disabled. Successively, output signals of the comparators 42_1 and 42_2 are respectively inputted to a logic means 44 which generates the switching control signal S_N which is delivered to the filter. For example, the logic means 44 generates logic 1 when the filter shall be enabled, and logic 0 is generated when the filter shall be disabled.

The quality measurement Q_N which is able to cancel the greatest echo will be the first filter to exceed the first threshold value Tr1. This is why the first filter has a relatively large output signal and a relatively small error signal. As a result of enabling or coupling to the first filter, the error signals for the remaining filters will be reduced by the value of the output signal of the enabled filter, since this output signal is subtracted from the echo-included signal in the subtraction means. The quality measurement of remaining filter will increase therewith.

Further, the error signals of the filters that are not enabled will be also reduced for each new filter which is enabled after the first enabled filter. Consequently, the smaller echo will be initially hidden by the larger echoes. No significant work can be performed by the filters. That is, the only small echo signals can be canceled by the filters. The input signal, however, is so small that its quality measurement cannot exceed the filter enabling threshold value Tr1. The foregoing filters will never be enabled.

When a filter is enabled, its quality measurement will be slightly reduced. This results from the fact that the signal E_{TOT} is reduced by the filter output signal.

A filter coefficient will be converged when an echo signal is generated by the speech signal including an echo signal from an opposite person. Further, the filter coefficient will be disturbed by the speech signal including the echo signal from a user himself.

As mentioned above, the echo canceler may repeat the convergence and disturbance of

the filter coefficient. As a result, it takes long time to update unnecessary filter coefficient each time.

Summary of the Invention

It is an object of the present invention to provide an echo canceler with functions as follows:

(1) to prevent a speech signal including an echo signal from a user himself from disturbing a converged filter coefficient;

(2) to reduce performing time in a position where an echo signal is highly delayed; and

(3) to efficiently converge a filter coefficient.

According to a feature of this invention, an echo canceler comprises a plurality of cascade-connected adaptive filters, an update control means generating an update signal for updating filter coefficients of the filters in correspondence with the power of each opposite speech signal from the filters, and a subtraction means generating each of error signals to the update control means after receiving each of output signals from the filters and then canceling echo signals from echo-included signals. Herein, the update control means and the subtraction means are respectively equipped in correspondence with the filters.

In a preferred embodiment of this invention, the update control means generates the update signal by which a filter coefficient of its filter is updated when the power is larger than a threshold value of the filter, whereas the filter coefficient is not updated when the power is smaller than the threshold value.

In the preferred embodiment of this invention, the update control means comprises a comparator receiving and then comparing the power and the threshold value, and a logic circuit

generating a signal for updating the filter coefficient when both an output signal of the comparator and the error signal are received and then activated.

According to another feature of this invention, an echo canceler comprises a plurality of cascade-connected adaptive filters, a selective means for generating a selective signal for updating filter coefficients of the filters in correspondence with each opposite speech signal from the filters, an update control means for updating the filter coefficient when the selective signal is received and then activated, and a subtraction means for generating each of error signals to the update control means by receiving each of output signals from the filters and then canceling echo signals from echo-included signals. Herein, the update control means and the subtraction means are respectively equipped in correspondence with the filters.

In another preferred embodiment of this invention, the update control means includes a logic circuit for updating a filter coefficient when the error signal and the selective signal are received and then activated.

In another preferred embodiment of this invention, the selective means controls the number of the selective signals in correspondence with the performing speed of the filters. Herein, a selective signal makes an update control means enabled.

According to the present invention, it is decided whether a filter coefficient will be updated or not by enabling or disabling an update control circuit by means of a power value of an opposite speech signal from an adaptive filter.

Further, an update control circuit is controlled in order to adjust the update of a filter coefficient by equipping an update control selective circuit which generates a selective signal for enabling or disabling the update control circuit by receiving the opposite speech signal from the adaptive filter. An echo signal calculated from each of filters is canceled from an echo-included

signal generated through an echo path.

Brief Description of the Drawings

Fig.1 is a block diagram illustrating an arrangement of a conventional echo canceler;

Fig. 2 is a block diagram illustrating an arrangement of a selective circuit generating a switch selective signal illustrated in Fig. 1;

Fig. 3 is a block diagram illustrating an arrangement of an echo canceler according to a first preferred embodiment of this invention;

Fig. 4 a block diagram illustrating an arrangement of an update control circuit illustrated in Fig. 3;

Fig. 5 is a block diagram illustrating an arrangement of an echo canceler according to another preferred embodiment of this invention;

Fig. 6 is a block diagram illustrating an arrangement of an update control selective circuit illustrated in Fig. 5; and

Fig. 7 is a block diagram of a control selective circuit illustrated in Fig. 7.

Detailed Description of Preferred Embodiments

Hereinafter, the preferred embodiments of this invention will be described in detail with reference to accompanying drawings.

An echo canceler of the present invention includes between two lines included in a four-wire loop a plurality of filters for canceling echo signals. Since the echo signals may have different echo signal delay time depending upon circumstances, the number of taps in the echo canceler will be decided by the circumstances. If decided, the number of taps is allotted to a

plurality of adaptive filters.

The allotting method may be 1/N(the number of a filter). Also, various allotting methods may be adopted depending on what filter cancels echo components, and when the echo components are canceled. For example, assuming that sampling frequency is 8 KHz, the number of the adaptive filter is four, and echo signal delay time is 32 ms, then, a first adaptive filter cancels an echo signal of 0-8 ms, a second adaptive filter cancels an echo signal of 8-20 ms, a third adaptive filter cancels an echo signal of 20-28 nm, and a fourth adaptive filter cancels an echo signal of 28-32 ms. In this case, the number of each tap may be defined as 64, 96, 64, and 32 (total: 128 taps).

Referring to Fig. 3, the echo canceler 100 comprises a plurality of cascade-connected adaptive filters 102_1-102_N, a plurality of update control circuits 104_1-104_N each corresponding to each of the filters, a plurality of subtraction circuits 108_1-108_N each corresponding to each of the filters, and an echo path 106 where echo signal emerges.

The adaptive filters 102_1-102_N calculate an echo signal by receiving an input signal X (that is, a speech signal of a phone user himself or a speech signal from the person at the other end of the call ("an opposite speech signal"), and an echo signal). Afterwards, calculated output signals Y_1-Y_N are canceled from an echo-included signal D generated from the echo path 106. Thereby, an echo signal is canceled. Filter coefficients of these filters 102_1-102_N are updated by receiving update signals corresponding to error signals E_1-E_N from the update control circuits 104_1-104_N. As shown in Fig. 3, an error signal is corresponding to an update signal. The update control circuits 104_1-104_N respectively receive power values P_1-P_N of the opposite speech signal from the adaptive filters 102_1-102_N and the error signals E_1-E_N from the subtraction circuits 108_1-108_N, and activate or inactivate the update signals depending on the power values P_1-P_N.

Referring to Fig. 4, an update control circuit 104_N comprises a comparator and an AND gate. The comparator receives a power value ℙ on a non-inverting terminal and a threshold value TR on an inverting terminal. The AND gate receives output of the comparator and an error signal E_N and generates an update signal E_N. When the power value ℙ of the opposite speech signal is larger than the threshold value TR, the update control circuit 104_N generates the update signal, thereby, updating a filter coefficient of an adaptive filter shown in Fig. 3. When the power value ℙ is smaller than the threshold value TR, the update signal is disabled to omit updating the adaptive filter coefficient.

Referring to Fig. 3 again, each of the subtraction circuits 108_1-108_N cancels each of the calculated echo signals (that is, output signals Y_1-Y_N) of filters 102_1-102_N from the echo-included signal D. The resultant error signals E_1-E_N are applied to the update control circuits 104_1-104_N, respectively. Each of the adaptive filters 102_1-102_N, therefore, cancel echo components in a predetermined time period after generation of the opposite speech signal through a speaker of a portable telephone. That is, only when a filter coefficient need be updated, the filter coefficient is updated by an update control circuit 104_N.

By using an NLMS (normalized least mean square) algorithm, a filter coefficient ***mu*** is obtained as follows:

[Equation 3]

$$\boldsymbol{mu} = (2*\mu*\mathrm{e}) / \mathbb{P}$$

$$\Delta \mathrm{H} = \boldsymbol{mu}*\mathrm{x}$$

$$\mathrm{H} = \mathrm{H} + \Delta \mathrm{H}$$

In the [Equation 3], "μ" is a constant, power value $\mathbb{P}$ is a magnitude in a random interval of the opposite speech signal, "e" is a filter error signal E_N, and "H" is a convergence constant. In particular, the filter error signal e is obtained by subtracting an output signal Y_N from an echo-included signal D of a user's speech signal. For example, if there is only the speech signal of the user, the filter coefficient should be not altered. The "P" is small and the "e" is large, thereby increasing "***mu***". Consequently, the "ΔH" is altered to exert a bad influence upon the convergence. If there is the opposite speech signal, the "$\mathbb{P}$" is large and in inverse proportion to "***mu***". However, the "e" is proportion to the "***mu***". Since the filter coefficient moves to the convergence direction, it will be continuously updated.

In case of a double talk that is a mixture of a speech signal of a person himself and an opposite speech signal, the "***mu***" is highly altered and the filter coefficient repeats the convergence and the disturbance. It is therefore decided if the filter coefficient is updated by enabling or disabling the update control circuit with the power value of the opposite speech signal.

Fig. 5 is a block diagram of an echo canceler according to another preferred embodiment of the present invention. Referring to Fig. 5, an echo canceler 120 for cackling echo components in the limited performing time, comprises an update control selective circuit 130, a plurality of adaptive filters 122_1-122_N, a plurality of update control circuits 126_1-126_N respectively corresponding to the filters 122_1-122_N, and an echo path 124.

The adaptive filters 122_1-122_N calculate an echo signal after receiving an input signal X including a speech signal of a user himself or an opposite speech signal and an echo signal. Then, output signals Y_1-Y_N (that is, echo signals) of the adaptive filters 122_1-122_N are canceled from an echo-included signal D generated from the echo path 124. Opposite speech signal power values

P_1-P_N calculated from the input signal X are supplied to the update control selective circuit 130. The update control selective circuit 130 generates selective signals S_1-S_N which enable or disable the update control circuits 126_1-126_N, respectively. Filter coefficients of the filters 122_1-122_N are updated by receiving update signals from the update control circuits 126_1-126_N which generates the update signals by receiving signals E_1-E_N and the selective signals S_1-S_N. As shown in Fig. 5, the error signals E_1-E_N are correspondent with the update signals.

The subtraction circuits 128_1-128_N cancel from the echo-signal D echo signals (that is, the output signals Y_1-Y_N) of the filters 122_1-122_N, respectively. The error signals E_1-E_N obtained from the subtraction circuits 128_1-128_N, respectively, are supplied to the update control circuits 126_1-126_N, respectively. Thus, the echo canceler 120 cancels from the echo-included signal D the output signals (that is, the sum of echo components) generated from the adaptive filters, respectively.

Referring to Fig. 6, an update control circuit 126_N comprises an AND gate. When an error signal E_N and a selective signal S_N received through separate input terminals are activated, the AND gate generates an update signal.

Referring to Fig. 7, the update control selective circuit 130 generates the selective signals S_1-S_N to be used for updating the filter coefficients. That is, the update control selective circuit 130 generates the selective signals S_1-S_N for enabling or disabling the update control circuits 126_1-126_N by receiving the power values from the adaptive filters 122_1-122_N. The number of enabled selective signals S_1-S_N is decided depending upon the performing speed of the echo canceler 120.

Thus, it is possible under circumstances of long echo delay time to cancel an echo signal with the long echo delay time by using many taps and to enhance the performing speed of an

echo canceler by updating the filter coefficients.

Although various modifications may be suggested by those versed in the art, it should be understood that the present invention embodies all such modifications as reasonably and properly come within the scope of its contribution to the art.